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Good morning welcome to session 3 of the asteroid grand challenge anniversary seminar series. It is my privilege to be sitting next to David Morrison the senior scientist here who has been gracious enough to spend some time with us explaining what really makes the grand challenge to find asteroid threats David has inspired many of the asteroid hunters that are doing this professionally and we all still have a lot to learn from David. I would like to turn it over to David and hopefully we can get a little smarter within the next hour.

Thank you. It's a pleasure to be here and talk about asteroids. I've been in this business for 25 years since I gave first talk to stoppers in Congress to talk about the fact that there was an impact hazard. I'm grateful for the step forward with NASA actually officially making an asteroid grand challenge that's why dreamed of for all of those 25 years. We were trying to sell this and explain what the asteroids were and why they were a challenge. Let me say, the grand challenge has the -- the word asteroid in it. I cannot advance my slides. There this is the grand challenge. It's about asteroids that threaten the earth and I should say that this is near Earth asteroids by definition these are not the asteroids that live in the asteroid belt between Jupiter and Mars. It's a much smaller number they are smaller, those orbits close to the orbit of the Earth. It's a relatively small number compared to the main asteroid belt nevertheless there are at least one half million of these near asteroids that could threaten human populations. They could do severe damage if they hit the earth. Finding have to million asteroids and trying to understand their orbits and with the possibilities are of impacting the earth is indeed a grand challenge.

For so many people, the thing that's quite your attention was the impact explosion in the atmosphere above Chelyabinsk Russia on February 15 of last year. A projectile that came out of nowhere about 15 minutes after sunrise came from the direction of the sun so no one saw it coming. It exploded in the atmosphere. With an energy of about 1/2 Mt which is as large as most of the nuclear weapons that have been developed fortunately it exploded at a high altitude and so it did not do very much damage on the ground still it was a spectacular events.

Here are some pictures you have probably seen the videos.

The damage it did was from the shockwave. It broke thousands of Windows and injured about 1000 people from flying glass. The message here is if you see a bright light from a meteor in the sky do not walk over to the window to look. Because if they stayed away from the windows, there would not have been any casualties.

Here are pictures of what it was like and how they found the media rights. Meteorites are fragments of incoming objects. And so the were tens of thousands of these little black stones scattered over the snow since it was winter they were easy to find. You can

imagine thousands of children going out in the farmlands around Chelyabinsk picking up these little rocks that were lying on the surface of the snow. About three days later it snowed again and it was difficult to find them. The largest which made this round hole weighed 1 ton. Most were just little pieces.

This impact took place in Russia in the Ural Mountains it was near a city of 1 million people so it attracted a lot of attention. Much less attention at the time came from the previous -- previously impact. Also in Russia and Siberia, in 1908, this was a much bigger explosion. This was equivalent to about 5 Mt which would be equivalent to a very large nuclear explosion. It level M km² of forest. This was of a scale that would truly destroy a city. And could kill millions of people. If you imagine it coming in again much more of the earth is populated. It was an example of a larger story asteroid about 40 m in diameter as compared with the 20 m diameter for the Chelyabinsk meteor .

Let me explain why we care about an EA's. They are a significant component of our solar system. They are the leftover building blocks from the plans and so scientists are interested in understanding them -- how they got there and what they are made of and so on. They are potentially steppingstones on the way to Mars. NASA's long-term objective is to send humans to Mars and to do that we need to expand the envelope for human spaceflight. We need to understand how people can live for long periods of time once or even years, in space, to deal with hazards there like cosmic rays. So the only thing between the moon and Mars are thousands of asteroids and we want to visit one or more of those taking that is the way to expand our capability with the ultimate goal of landing humans probably first on the moons of Mars and then on Mars itself. The grand challenge emphasizes the fact that these asteroids do hit the earth that they are a significant risk and so planetary defense is another primary motivation for understanding the near asteroids. The people who are interested in space resources in mining asteroids also look to this same population. The nearer the asteroids are two places that you would go to extract minerals, water, and other materials, if you had a robust if a structure in space, if we were truly a space bearing nation or space during civilization, and all shortly we would be making extensive use of the near asteroids for the resources. And for all of these reasons there's a general interest including the fact that the president of the United States made an official statement about four years ago in which he said that the next goal for human exploration should be to visit an asteroid. As part of this long-term desire to eventually send humans to Mars.

I got into this business a long time ago chairing the first NASA workshop which was mandated to the Congress to understand what the risk was -- was insignificant, or the objects that it produced a risk and could hit the earth? And we came up with a very influential report on the near Earth object detection workshop and recommended what is called the space Gard survey. Which has been happening now for almost 20 years. A survey to find the larger near Earth asteroids. We started this business we only knew of 100 now we've just crossed the 11,000 mark in the number of near asteroids that been discovered that his does that is very impressive but it still leaves with a half million undiscovered.

Let me just summarize here before we go into the details. The cosmic impacts by comets or asteroids mostly by asteroids, are truly the most catastrophic natural events we know of. They exceed the worst that could happen with a walk-in at the Russian, or an earthquake, or any other natural hazard that we know of. While they are very rare, it certainly makes sense that we should want to understand this population of objects and the risks they pose. The chances that you will die from an asteroid will say on your tombstone killed by an asteroid, are quite low. I'm sure you do not know anyone who has been hit by one. No one in your family was ever killed by an asteroid impact no one in all of history was ever killed by an asteroid. With his casualties take place, they take place in large numbers that is, the only size asteroid that can do an asteroid goes back and do damage is one I can get through the atmosphere and explode with the energy of a nuclear bomb so it's an example of a risk of Barry low frequency but that's compensated by very high consequences. If you want to deal with this impact risk or to any of the other things with near Earth asteroids like mine them for resources or use them as steppingstones to Mars, you have to find them. The first most important task in this activity are to find the near Earth asteroids and track their orbits. The second most important thing is to find them and track their orbits. The third most important thing is to find them and track their orbits. If you have not found them, then all the rest is just aren't waiting. -- Arm waiting. The motivation for finding them is not the science per se, it is for safety. We do this because the Congress has mandated for NASA to do this, the United Nations has recognized this because finding an understanding near Earth asteroids is a way to protect us and our populations from threatening objects.

This is a chart that gives you an idea of how many of these objects there are. There are many more small asteroids than large ones. As represented by this line and its expressed here not in terms of the number of near Earth asteroids but the frequency with which they hit the earth. So if you go down through this, we could start at the top with something the size of the Hiroshima atom bomb. That is about 15 kt of explosive energy. When we first made this graph, I must emit with all we have done something wrong because this says that that sort of Hiroshima sized explosion should take place about once a year on the earth. And that defined common sense -- how could there be something 15 kt happening every year and we never heard of it and it was not in the newspapers, it was not known to the public. The answer is those explosions take place very high in the atmosphere. Objects of the scale to produce eight to receive bomb explosion break up high in the atmosphere explosion is indeed there, but no shockwave reaches the ground. Now, we are using other resources are merely from the Department of Defense and Department of energy that are able to measure those objects exploding in the upper atmosphere. Or even measure the first-round -- in for sound from those explosions and we verify that there is indeed the size of once a year. That is a firmly anchored data points. The others we built a priority not this curve lets us read this off. A Tunguska impact at about 5 Mt happens once every couple of centuries. Down at the far right KT stands for the impact that killed the dinosaur. Which is truly fast. That was a 10 to 15 km diameter asteroid and the energy released was 100,000,000 Mt. Far far beyond the scale of all of our nuclear weapons put together. Fortunately that is not happen very often. We estimated as about once every 100 million years. And so that defines pretty much the upper limit something that could cause

a mass extinction. We're not worried about that now because one of the first results of our space survey was to recognize that there are no near Earth would -- asteroids that can hit the earth of that size. There are no 10 or 15 km diameter NEAs and we do not have to worry about a mass extinction but there are lots of NEAs and the one or 2 km in smaller sizes and those what we focus on those of the ones we want to discover and characterize and predict their orbits and if any of them is now or should in the future on a collision course with our planet, then clearly we need to know that.

This is a picture to give you an idea of what we're talking about when we talk about near Earth asteroids. They are not simple round spheres. They are small and the regular -- irregular. This was visited by a NASA mission in 1996 and landed 2001 it orbited and landed on the surface in 2001. This was our first close-up look at a near Earth asteroid the first chance to measure its composition, by landing on the surface. It did not look like anything we had seen before that is because it is small. Small enough to be irregular unlike a planet or moon which its own gravity pulls it into a spherical shape.

This is another near Earth asteroid. This was visited by the Japanese mission in May 2003. It reached the asteroid in 2005 and was designed not just to land on the surface but to collect samples. And bring them back to earth. So we not only had to details of this we have samples, there is small samples that have been returned for analysis in our laboratories. That's very important because if we ever want to understand these objects better, if we're ever faced with trying to defend ourselves by shooting down one of them, then its composition is very important. It also links the observations and actual near Earth asteroids with meteorites. Meteorites as I think most of you know, are fragments of rock that have come to earth through space. They are usually pieces of bigger asteroids and we have 50,000 meteorites. There are lots of them that have been collected. This begins to allow us to put them in context because they did come from near Earth asteroids that are no longer there. And clearly if we can use analysis of those meteorites that gives us a powerful insight into the range of compositions of near Earth asteroids. That range is very large. At the simplest level, it goes from iron nickel objects heavy clumps of metal down to extremely loose objects that are made of unchanged chemical materials from the formation of the solar system. We call this primitive meteorites. And in that case, these are so soft and delicate that they disintegrate. They might be somewhat like the composition of a charcoal protect that you could crush in your fingers. That is a whole range in between of combinations of rock and metal and this light material. One asteroid can often contain several different kinds of chemistry because they are made up of materials that have come together. If you look at the shape of this asteroid you can see that it is one big piece and another smaller piece attached to it there is no reason to think those two pieces of the same opposition. So asteroids are complicated.

The next image shows one case where NASA has set -- send a spacecraft that you just to fly past the asteroid will land on it but to hit it at high speeds. To make a crater and look at the nature of what came off. This was done for comment temple one not an asteroid but sets the stage for what you might have to do if we ever are going to deflect an asteroid from hitting the earth. The most straightforward and simplest way and I will talk about this more would be simply to run a spacecraft at high speed into the comment. The flash

of light here the energy you see is not because the spacecraft carrying a nuclear weapon or even TNT, it's just the kinetic energy of the impact.

Let's turn next to the ultimate motivation because while scientists have been very interested for a long time in this problem, it has received many boosts from specifically from the U.S. Congress and the House of Representatives where a number of people have been pushing NASA all along for 20 years to carry out something like the asteroid grand challenge that we have today. The first statement was back in 1991. I really like it. It's right on target. Read especially the last sentence -- the chances of the earth being struck by a large asteroid are extremely small but because the consequences of such a collision are extremely large, the committee believes it is only prudent to assess the nature of the threat and prepared to deal with it. And that's precisely what we have been doing for the last 20 years. Especially the assessing the threat. We have not gotten a long way in figuring out what to do about it but we are discovering a lot of near Earth asteroids and understanding them.

This shows an update in 2008 by this time we had actually found almost all of the asteroids a kilometer or larger and now the Congress is asking us to move the goalposts down to objects 140 m in diameter. But it also is much more explicit about the purpose of doing these studies. This is not just assessing the risk, this is specifically to detect track, catalog, and characterize these objects. You have to do all of those first you have to find them, then you have to determine their orbits you have to publish the information, and you have to do characterization. And I should say, because sometimes people make strange accusations about what the government or NASA is doing, this is one of the most open things that we have. Every day, the observations even just from the previous night are put online and used to update the orbits that we have for these asteroids. You can go on the website at NASA and so on and see day by day with the progress of these surveys are and see for yourself which ones might come close to earth and whether you think there is a significant risk or not.

The next statement is interesting because for many years, someone facetiously, astronomers would say, if I found a near Earth asteroid that was headed for the earth, who should I call? What should I do? And in 2010, there was a formal answer to this from the White House that spoke for the United States. John Holdren issued this statement -- and it does assign responsibility. NASA retains the primary responsibility for discovery tracking and characterization and threat identification and notification. If you are an amateur astronomer and you find an asteroid headed for the earth, you call NASA. Specifically you call NASA headquarters and this was part this whole chain of activity going right up to the White House. There's always the possibility that we would be hit by something with little or no warning and for that, it's important that NASA work with the Department of Homeland Security and with FEMA because there you might have to deal with the actual consequences of an impact. Generally speaking, we do not want to have to do that. We want to find any threatening asteroids far enough in advance that we can change their orbits and the -- deflect them so they do not hit the earth. And for that NASA again, does its part which also works with other agencies like the Department of Defense. Some studies have gone on a discussion exercise with other agencies about how this might

happen. It's clearly an international problem because a priority all places on Earth are equally likely to be hit. And so the UN has taken a strong position and that is the official US government statement. There are now our official statements similar to this from the United Nations not quite as explicit, but again, talking about the need to set up processes for communicating and working together.

I've already told you -- you have to find them first. Next I will talk a little bit about different perspectives on this.

The first perspective is how we started. I have been saying that the initial task was to assess hazard. When we first said there might be a hazard, we had will be called the giggle effect. Nobody believed us. They thought he was a crazy astronomer. Because it never happened in history. So much of the early work was simply to make enough observations find enough asteroids, Catholic their orbits that we could say that there was a real hazard, that we were not just getting -- kidding around. And that is reflected in that first Congressional language that we should assess the nature of the threat. That was pretty easy. Once we did that, we shifted to a much harder task and that is actually providing the public and decision-makers information one warning and protection because let's face it, nobody was a decision-maker in the political chain is going to care whether there is a one in 1 million or one and 50,000 chance that something will happen. They want to know when and where the next impact will take place. That requires us to find every one of these objects eventually and put it either in the same category of put -- potential impact category. They want to know can we find the next object? So this is what the NASA and astronomers who work with NASA have been doing for the last several years is catalog as many objects as possible. And for each one calculated whether it actually is a risk or not. And there have been a few that have seen for a while as though they might be but I am happy to tell you, that we know of no near Earth asteroids now that is on a collision course with Earth. We do not know of any even that has a one in 1000 chance of hitting the earth. The main immediate result of our surveys have been to show that we are safe from all the objects we have found. 11,000 near Earth asteroids that been discovered are not in immediate danger to the earth. One half million others we have not discovered however they might be. We really have only begun to look compared to the magnitude of the task of finding these.

This is a different way of looking at it by perspective number three and this especially has been true since the Chelyabinsk meteor of February 15, 2013. And that is again, statement with politicians, they do not just want to know about the big ones that could destroy a city. They would like to know about the little ones also like Chelyabinsk. They would like to have warning even if it's only a few days. Which would not be enough time to deflect it but it could prepare a population -- could in fact treat the situation much the way in the US read -- we treat hurricane warnings. Usually three or four days before a Herbert hurricane hits one could tell approximately where it is going comments magnitude, you want people and in many cases, Florida and the Carolinas and New Orleans people can evacuate. So if you have that kind of warning even of a relative small impact, you could -- it would be worthwhile. You cannot save the infrastructure that might be damaged but you could save the lives. So this gives us another motivation that's

a different technology to find the objects that are small and close to the earth even though we cannot do anything about them at least people want to know what's out there that could hit us.

Next chart, this discusses the 's survey. That was the program that the group I chaired first in 1992 recommended to carry out this first survey in a systematic way. The name incidentally comes from a novel by Arthur C Clarke and Arthur Clarke who is many people's favorite science fiction offer those altar -- author we can use us for our survey system. The survey has evolved over time but for the most part, it's consistent of three or four modest sized telescopes. Telescopes of an aperture of 1 m. Certainly not the most powerful state of the art telescope but with really good detectors. Widefield images and computer analysis because humans could never find these think moving objects against the background of stars. It's a perfect place for computer analysis. Every night, these three or four telescopes are observing the data comes back and is analyzed. By the next morning, the following afternoon or -- they are posted on the Internet. Many amateur astronomers participate in the follow-up of these objects. The goal of to officially was to find 90% of the nearest objects larger than 1 km. We have done it. That goal has been reached. We now have 95% of the 1 km or larger asteroids but not so good on the smaller ones.

This illustrates this progress. This is the key relative number of known near Earth asteroids year-by-year. You can see we first started this background 1990, just a handful there were only maybe 100 near Earth asteroids that were known. You can also see on this chart is an inflection point where the rate of discovery increases sharply in 1998. Was there new technology in 1998? No. What happened in 1998 was money. That was the first time there was actually funds in the NASA budget to carry out the survey. And that a lot of us to support more astronomers and telescopes and have this discovery that you see here.

Were seen these objects and we have the orbits for all of them. The problem is that there are so many more out there. Whether we are motivated by scientific understanding of near Earth asteroids, or by finding targets for human landing, or by finding potential targets for exploitation in asteroid mining, or we're trying to protect ourselves we have to find more objects. And while the 's survey -- Space GAMBIT teen survey has been successful it's reached its limit . We can continue to operate to find about 100 new asteroids a month but it does not begin to address the real task of finding one half million. For that will most certainly need much better more advanced technology in space. An -- were put together a program with private donations since the US government and the UN and others have not yet willing to pay for a space-based infrared survey there is an effort to raise money and it if any of you listening has really rich friends, please talk to them for the cost of building one urban freeway interchange one could carry out the mission and find one half million asteroids. Some think that saving the earth is actually more valuable than building a freeway interchange. But that's a value judgment.

We do need to understand these objects better. The survey discovers them as points of

moving light in the sky. It does not tell us much about them for that we need other facilities the most powerful of which is radar. If these objects come close enough to the earth and they really have to come quite close they can be studied with the big planetary radar at various locations and for those objects we can get a lot of information interestingly, about one quarter of these near Earth asteroids they have little tiny moons around them. That allows you to do determine their mass. It's not clear how much we need to know. Initially. But if we ever find an object that is potentially able to impact the earth, we clearly are going to have to study it. Precursor spacecraft with ground-based facilities and the question is simply, how much money should you pay, how many resources should you put into characterizing objects now only have not found the one with our name on it?

Me talk about planetary defense. We do this because we actually think we could have the technology to stop an incoming asteroid not literally stop it but to change its orbit. What you are doing if you discover an asteroid and E its orbit 10 or 20 years in advance and find that there is a risk what you're saying is that after he has gone around the sun a number of times and the earth has gone around the sun, they will be at a same position at the same time. So to avoid an impact, you have to move either the earth or the asteroid. Obviously it's easier to move the asteroid. So what you need to do is make a very slight change in its orbit so that after it goes a dozen times around the sun it either gets to bear to the rendezvous point before the earth or after it. That just means changing its arrival time by a few minutes. So what we have thought about are the ways that you could change the orbit of an asteroid and the most simple and powerful weapon is just a kinetic impact. Just hit it with a spacecraft at high speed. You do have to hit in the front to slow down or in the back to speed it up. And this is something we are sure we could do but we have never tested it. There is no actual technical demonstration yet of our ability to change in asteroid orbit. We need that too if we're ever going to be serious about planetary defense. Which everyone pays lip service to but has not always been willing to put money into.

The next chart talks about these issues. Should we develop the technology for asteroid the flexion now? Or wait until a specific threat is identified? Most of us would say, we need to do some technology will develop now. We do not want to put it all off. Should planetary defense be an international effort? Yes everybody is at risk. Everyone should be interested. But the fact is that only a few space bearing nations have the capability to mount a mission to do a deflection. The US is certainly Russia, China, maybe a few others Japan, but it's interesting that almost 1% of the money that has been spent into this whole process of surveying and understanding. Asteroids is from US. Japan is the one exception or they are highly successful. But otherwise this has been pretty much a US game. How much should be spent to protect the planet? That's always the question if it's public money, in the US it have to go through the Congress which has been supportive but has not been willing to specifically build a space detection system which is the first step. That is why the Sentinel program is trying to raise money and that is why we hope that there are some billionaires in Silicon Valley for example that thinks saving the world is a good use for some of their funds. It became to actually defending against a near Earth asteroid, the US is probably has the greatest capability in terms of doing it. But do you

think the rest of the world would trust the US alone to take responsibility for protecting them from an incoming asteroid? I do not think so. It's actually this is a major issue for the UN. It's very tricky to know how we can work collectively when only a few countries actually have the technical capability to do this. And then finally, there's a question always raised, if you build a new defense system, could it be misused in one way or another? That's a question you always have to ask.

Next is just to mention again international programs. The UN has been studying now for almost 10 years they have a UN action team there are many dozens of nations that are involved one way or another in looking at these issues. But we have made great progress but are still not on the critical steps of doing a space based survey or of testing the technology or deflection. Let me conclude with the next chart.

Let's think about the dinosaurs. Much -- most of this became aware of this when we learned that the mass extinction that killed the dinosaurs was due to an impact. The dinosaurs were big and strong and beautiful and pretty intelligent if you have ever seen drastic park you know that. The occupied environments all over the planet which is usually the best way -- the best insurance against extinction. They had ruled the world in the sense of being the dominant animal creatures for 100 million years which is a long time. But, they did not have telescopes and they did not have space programs. They could not have detected the incoming object and even if they had they could not have deflected it. We do have that capability. We do not need to suffer the same fate as the dinosaurs.

This is another way of looking at things. Some people have quit the asteroids are nature's way of checking on our space program and how we're doing. So that's my presentation.

Fantastic, David. Thank you so very much it's a wonderful to have all the wisdom and experience you bring to think about this problem and your willingness to share it with us. I want to invite everyone that's tuned in if you have not already asked a question in the chat box feel free to do so. This is a rare opportunity for some to be able to get a chance to talk with and -- and ask questions with David Morrison. I will ask some of the questions that have come through the chat window. The first one we have is if we want to land on some asteroid what mobility method will be used under low gravity?

That's a good question. What astronauts have talked about what it would be like to visit in asteroid. The first thing you think of is footprints. Asteroids are low gravity in fact the astronauts have said operating on an asteroid will be operating on a space station. You would just float around. Mobility in a sense it's very easy you could just stand off and move around like you're flying. But mobility in the sense of being anchored to the surface and digging for instance actually is quite a challenge.

Next one, then you 2011 and if the only one with non-gravitational parameters determined?

I am no expert on that asteroid but I have heard the discussion here yesterday. It is so small that we have been able to measure a change in its orbit due to the pressure of sunlight. A big object sunlight does not make a difference but if it's small enough, and one of the interesting things you can conclude from that is something about its density. A low-density object will be moved more by sunlight than a heavy one. And it turns out to be low-density. Perhaps even lower than the density of water. Now since it's obviously not made of water or ice but of rocks, that means the rocks are very loose -- loosely packed. This is one of the things we have suspected about a number of near Earth asteroids they're not monoliths they are not solid pieces of rock. They have experienced impacts in the past and have broken up and they can have very unusual interiors with high velocity. So we do not know how they would respond to being hit with a rocket or something of that sort.

Important for us to get out there

I think it is important yes

There is such a wide variety of asteroids that even if we study two or three in detail, the chances are the one that has our name on it will still be different.

Here we have a question I'm beginning to work in photometry. What types of asteroids should I focus my attention on. Is it more important to look at poorly observed asteroids or to be -- or to continue to define a previously studied asteroid?

That is a good question and a difficult one. I will give you my perspective on where photometry will be the most useful. The small asteroids, the ones that could be targets for human missions or are most likely to hit the earth, seem to be quite different physically from the larger ones. They tend to rotate very fast. Sometimes the asteroid will rotate in just one minute or two. Completely different from what you normally think of where it takes hours. In photometry is the way you can determine those rotation periods. Because of its elongated as it rotates it will go up and down. So I think from my perspective what we really would like to have people do is try to observe these very small ones that are close to the earth when they are bright enough and all you have to do is observe them for one hour to get a light curve of the like going up and down until it belongs to it and there are and what the rotation is. If I were picking -- I'm focused on the targets of opportunity with small near Earth asteroids close to the earth and wide enough to see.

Is another one. I think it relates to what we're talking about yesterday. How immature astronomers can get involved in searching for NEAs ? Is there a database we can analyze?

That was indeed discussed yesterday. I don't know of any public or any existing set of images at all. There may be but basically when the professional surveys take place, they take lots of images and the computer immediately looks for the moving objects. And so

that's what you keep is the information on the moving objects. I suspect that there is more opportunity for amateurs to make these follow-up observations and to go back and look at the original images. Original images have been searched on computers that are designed to look for moving objects. But I cannot know there may be images and maybe possible to do more work with them but I think the characterization and the follow-up is more interesting.

I do believe we will be having an asteroid so coming out through the platform that resource platform is the mining company would make available some of that but like you said I think this is data that has already been looked through initially. Why not harvest asteroids to guard dog earth and hit larger asteroids save sending a big rocket up.

Committee idea of hitting a half-mile wide incoming object with a 1 m wide object that's already here is a lot harder than shooting a rocket added. It would take rockets to take your little one and aim it at the big one and you do not have the control that you have with an actual rocket. So I think that is not -- in principle you could do it but it is not the easy way. Easy way is to launch a rocket from birth with all the control and capability we have home in on the object you are going to hit and hit it

Easier than a game of pool

I think so

Were -- you have thoughts on where you can send a theoretical work on earth defense from asteroid threats?

Most things like this are published in scientific journals. I don't know if NASA would like to receive such a thing

We are accepting all sorts of ideas from folks. So that could be a place to share that

Can you tell people?

We will put the address in the chat window. There it is popping up right now. You could link to that site and share your ideas.

Any suggestions for capture systems to stop a 1 km wide asteroid?

I do not think that capture is really relevant here. You simply need to change its orbit. If its orbit is such that it will collide with Earth and you give a slight change that's a permanent change. It's never going to come back. So from a defense point of view, you deflected and that is the easiest thing to do. The question of asteroid mining is very

different. And I don't know what those companies plan on doing but I suspect they are not talking about killing meteor sized asteroids.

Do you personally they were a grab a small boulder version of ARM

I am no expert on ARM I don't think either of those approaches will be a major advance from the planetary defense point of view. It will teach is about asteroids and that is good. But I don't think it's nearly as important from the defense perspective as carrying out a survey and doing a bunch of low-cost characterization listens -- missions.

Can we bring some small asteroids and use them as platforms for experimentation or technology development cost in?

That's a cool idea. That's very much along the lines of what the asteroid retrieval missions are talking about doing. And if bringing 1000 ton rock into that space is useful to the space resources people, that's great. I think they would love it but you should talk to them.

Along the mining theme can a larger asteroid be used as a manufacturing or supply base I would think if we were able to stabilize and asteroids orientation we could use the rock of the asteroid to shield against radiation.

Interesting idea. We have an actual example of that. [Indiscernible] the two moons of Mars which are probably captured asteroids from long ago. They provide just that kind of opportunity for astronauts to make their first visit to Mars. Do not just go in orbit around Mars you Woodland on [Indiscernible] and use this as a shield to protect you from cosmic radiation. And that's a good idea. Now in terms of looking at an asteroid by itself, it's not easy to slow down the rotation of an asteroid. And so you just have to ask about cost-effectiveness. Is the fuel to slow down and asteroid rotating -- out of that balance against a little more shielding from the astronauts on the spacecraft? Interesting question

Could we park defensive spacecraft to intercept asteroids?

We've talked about that before. If we could park and asteroid but if we want to intercept one you have to accelerated to very high speeds and send it off in the right direction and I still think it would be easier simply to launch a rocket from the service. Your statement about multiple [Indiscernible] would take a great deal of skill to do that properly.

This relates into this next question of how controlled is the flexion? What if it will start an avalanche of event were later we have a bigger rock coming?

You have to think about that. Because we honestly do not know very much about how a particular asteroid would respond to being hit with a deflection. It might break apart. One

of the interesting techniques that I did not talk about is called the gravity tractor. And that allows you to make fine adjustments. So you might have a major smash into it and change its orbit, and then just to make sure that none of the pieces go anywhere you do not want, you could set your spacecraft next with with a low thrust propulsion and just the gravity between the spacecraft and the asteroid is enough it's like a rope pulling it and that sort of gravity tractor is it's a low thrust and it is precisely what you would want to do after a major change in orbit to make sure you had not had unintended consequences that the pieces are also going to continue to miss the earth.

Long-term can you end up changing so many trajectories that you are actually juggling asteroids?

That's very long term. We're talking about carrying out a survey that might require us to deflect one asteroid in the next 45 years. That's certainly what doing at that asteroid is ready for a it's worth deflecting. But you are not messing with the whole asteroid belt. It's interesting idea though

While looking for NEAs and other objects that make it is are we worried were looking at these objects potential to the other planets moons and the sun and what broader affect that might have?

We look and you probably know that there is a comet going very close to Mars right now. We discovered it here on earth and calculate orbit and found it went close to Mars. There was a suggestion a year or so ago of a small asteroid that might hit Mars it turned out that the lower court was refined. As long as we're living on earth it's earth we want to protect. And I do not think that there's any problem in fact one of the interesting discoveries made on Mars by the orbiting spacecraft is a new crater that was formed and we know the very date it took place from an impact. And so it's a crater about 100 feet across. But frankly nobody was on Mars and that's just a natural process that happens all the time. So I'm not going to worry about that. Hitting the sun certainly wouldn't do anybody any harm.

Is that a place where we might want to direct threatening asteroids towards?

That's one way of getting rid of it but it would take a tremendous amount of energy to change its orbit so much that it would hit another planet. So just nudging it so it will miss the earth seems the most practical thing that we could do.

Could impact measurably alter the orbit of [Indiscernible]?

Deep impact hit Temple one so it must've changed its orbit. But we do not know. For two reasons one is Temple one was a lot bigger than his asteroids were talking about, but more to the point we do not leave a spacecraft there to track it. The way you track the

orbit of an asteroid really precisely is to put a rendezvous spacecraft there attract the spacecraft. In the case of the impact it went right on past. So there's no way to tell within a very small change in the orbit.

We are near the top of the hour. I wanted to close out a question with a question about what you got -- what got you started in this? You have been here longer than anyone I can think of. I'm curious what was the spark that got you started because maybe we could replicate and get some new David Morrison's out there as we continue this conversation.

I have been studying asteroids as an astronomer for many years. When the discovery was announced in 1981 that it was an asteroid impact that had killed the dinosaurs, that was a really major almost a scientific revolution. Because while we all understood the impact takes place you look at the impact of the craters on the moon, you know that we had not realized that it could have a profound effect on Earth systems and life. So knowing that these asteroids could produce a mass extinction on earth motivated me to ultimately with my colleague to do these first elementary calculations how much risk was there? And what we found out there was risk we thought we should do something about it. One of the things we said in our first paper was that the risk of you dying from asteroid is comparable to the risk of flying in a commercial airliner once a year. And that certainly not a large risk but it's something we can understand and that motivated us to say, this really is worth doing something about.

Very good. Thank you, David. It has been a fantastic start to the day. I appreciate your time. I hope those that tuned in got their questions answered. Those that watch the recording we will be continuing this work that David has gotten us started with. Again, thank you everyone for tuning in.

Let me thank you, Jason for the asteroid Grand challenge. We have been talking about this for 20 years and NASA has actually stepped up to say this is worth doing. Maybe it will give you a lot of money

There are many other people to thank I just happen to be one of many. I invite everyone to tune in I can in 30 minutes we won't engage in an exciting conversation about the maker community and how can we engage the energy of the maker movement to help with the asteroid grand challenge. With that we will say goodbye for now and we will see you soon. Thank you so much. [Event concluded]